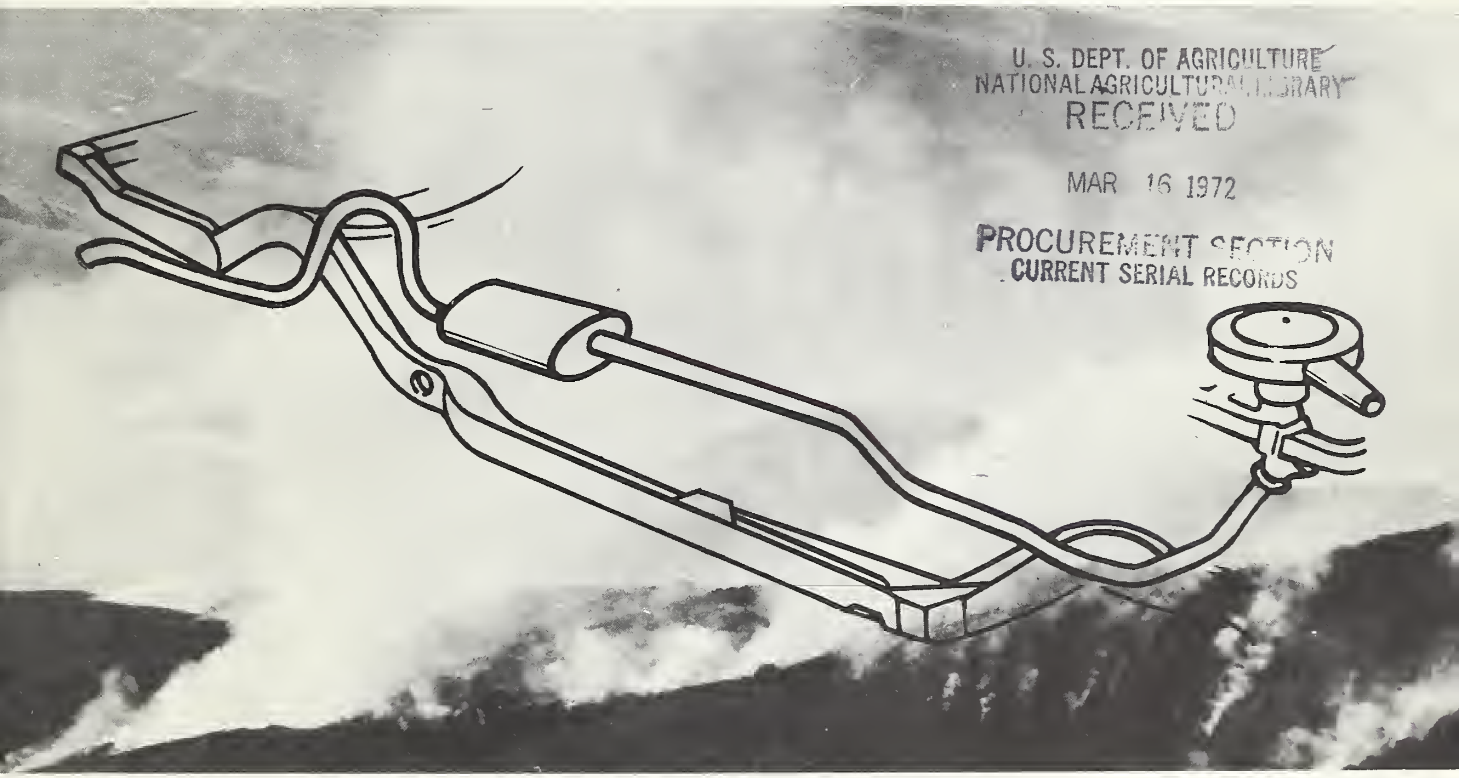
EQUIPMENT DEVELOPMENT & TEST REPORT 5100-15

DANGER OF IGNITION OF GROUND COVER FUELS BY VEHICLE EXHAUST SYSTEMS



U.S. DEPARTMENT of AGRICULTURE FOREST SERVICE

EQUIPMENT DEVELOPMENT CENTER SAN DIMAS, CALIFORNIA

NOVEMBER 1970

Equipment Development and Test Report 5100-15

DANGER OF IGNITION OF GROUND COVER FUELS BY VEHICLE EXHAUST SYSTEMS

ED&T PROJECT 1337

by
Rob Harrison, Project Engineer

U.S. Department of Agriculture, Forest Service
Equipment Development Center, San Dimas, California 91773
NOVEMBER 1970

DISCLAIMER

Information contained in this report has been developed for the guidance of employees of the U. S. Department of Agriculture - Forest Service, its contractors, and its cooperating Federal and State agencies. The Department of Agriculture assumes no responsibility for the interpretation or use of this information by other than its own employees.

The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval of any product or service to the exclusion of others which may be suitable.

Contents

INTRODUCTION

In the summer of 1952 the Forest Service Arcadia Equipment Development Center published a report on exhaust system temperatures of certain Forest Service vehicles (Ref. 1). That report concluded that the temperatures reached by these systems are high enough to cause ignition of ground cover fuels such as dry grass and pine needles. However, no recommendations for corrective measures were made at that time.

The intent of the current work was to re-examine the fire-starting potential of hot vehicle exhaust systems and determine if the risk is increased by the installation of anti-smog devices.

Three distinct phases of testing were undertaken:

1. The ignition temperature of certain ground cover materials was established by limited testing. Further work on this subject is to be done by the Northern Forest Fire Laboratory at Missoula, Montana.

2. Tests were conducted to determine exhaust surface temperatures of thirty 1960-and-later pickups and sedans. Half of these were equipped with exhaust control devices and half were not. The vehicles were tested on road courses and on a chassis dynamometer. Road tests produced probable maximum temperatures under normal operating conditions and dynamometer tests produced maximums that could be reached by pickups and sedans.

3. The final phase was to determine the changes in exhaust system temperature resulting from changes in engine parameters. Exhaust back pressure, ignition timing, etc., were varied during this phase of testing.

Some previous work along these lines has been documented by the Forest Service (Refs. 1 and 2), the U. S. Public Health Service (Ref. 3), and a committee of the Automobile Manufacturers' Association (Ref. 4).

PHASE I - IGNITION TEMPERATURE OF GROUND COVER

There is considerable diversity of opinion as to the ignition temperature of ground cover fuels. The ignition temperature is influenced by fuel size, type, density, moisture content, volatile content, compactness, air conditions, and so on. For forest fuels in air, in the absence of a pilot flame, this temperature has been reported to be as low as 400° F (Ref. 1) and as high as 838° F (Ref. 7). The investigations described here were intended to arrive at an approximate minimum ground cover ignition temperature in order to give meaning to temperatures of vehicle exhaust systems obtained.

Two types of ground cover were evaluated: dry annual grass and dead, dry pine needles. The temperature source used was a barbecue charcoal igniter with a thermocouple brazed to it. The temperature of the igniter was regulated by using a Variac as its input. Figure 1 shows the test setup in place on a fuel sample.

Figure 1. Ground-cover ignition-temperature test apparatus

Figure 2 shows time from contact of igniter and fuel to ignition as a function of igniter temperature. No grass was ignited at temperatures below 750° F for contact times up to 6 minutes, and no pine needles at less than 660° F.

Wind velocity had a marked influence on ignition temperatures. Environmental chamber tests indicate that a wind velocity of 2 mph leads to ignition with the lowest igniter temperature. With a wind of 2 mph, ignition in grass occurred with an igniter temperature of 760° F in 1.3 minutes, while with a 10 mph steady wind no ignition was recorded at 830° F.

For the purpose of further study of vehicle exhaust system temperatures, the surface temperatures needed to ignite ground cover on contact will be taken as 650° F. Nearly instantaneous ignition can be expected at temperatures of over 1,000° F, and ignition within one minute can be expected at temperatures of over 800° F. Reference 12 documents this phase of the test completely.

PHASE II - VEHICLE TESTS

Table 1 lists the fleet of Forest Service vehicles used to determine the surface temperatures of their exhaust systems along with some of the characteristics of the vehicles. Engine specifications are taken from Ref. 11. The vehicles were drawn from four Southern California Forests at random and represent three major American automobile manufacturers.

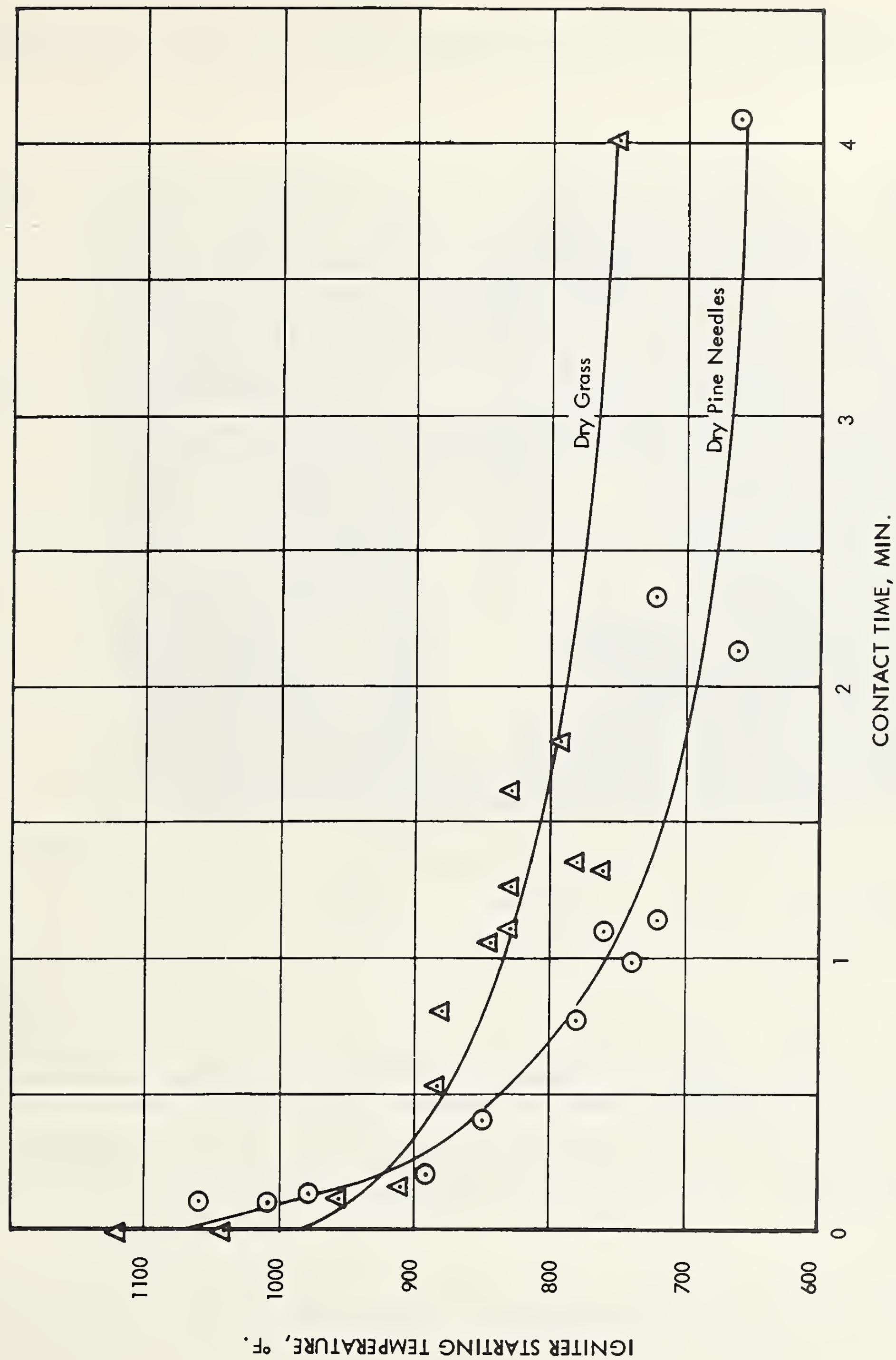


Figure 2. Ignition time versus temperature for two forest fuels

Table 1. Test fleet used to determine surface temperatures of exhaust systems

FS #	Year, Make	Smog Device	Owner Forest	Engine Displacement	HP @ RPM	Vehicle Type
280	65 Ply 6	No	Angeles	225 cu. in.	140@	Sedan
286	65 Ply 6	No	Angeles	225 cu. in.	4000	Delivery
428	65 Ply 6	No	San Bernardino	225 cu. in.		
223	66 Ply 6	Yes	Los Padres	225 cu. in.	145@	Sedan
226	66 Ply 6	Yes	Los Padres	225 cu. in.	4000	Delivery
227	66 Ply 6	Yes	Los Padres	225 cu. in.		
261	66 Ply 6	Yes	Angeles	225 cu. in.		
52	65 Ford 6	No	Angeles	240 cu. in.	150@ 4000	Sedan
17	66 Ford 6	Yes	Angeles	240 cu. in.	155@	Sedan
18	66 Ford 6	Yes	Angeles	240 cu. in.	4200	
3129	60 Chev 6	No	Angeles	235 cu. in.	135@	Pickup
3133	60 Chev 6	No	Angeles	235 cu. in.	4000	
3268	61 Chev 6	No	Cleveland	235 cu. in.		
3272	61 Chev 6	No	Angeles	235 cu. in.		
3877	66 Chev 6	Yes	San Bernardino	250 cu. in.	125@	Pickup
3880	66 Chev 6	Yes	Los Padres	250 cu. in.	3800	
3958	66 Chev 6	Yes	Los Padres	250 cu. in.		

The vehicles shown in Table 1 are typical of those found in service with the Forest Service up to 1968. During 1968 equipment engineers in the Northern Region reported exhaust gas temperatures in certain 1968 Chevrolet pickups which they considered to be abnormally high. These trucks are equipped with Air Injection Reactor exhaust emission controls (see Appendix). Since exhaust system surface temperature is directly related to exhaust gas temperature, it was felt that data from 1968 Chevrolet 292-cubic inch pickups and other late model vehicles should be included in this study.

Since these later model pickups seemed to indicate a trend towards increasingly hot exhaust systems, eight 1969 American sedans and one foreign car were also tested.

TEST METHODS, FOREST SERVICE FLEET

When a vehicle was received from a Forest, the first step was to install instrumentation on the vehicle. The instrument setup consisted of a recording oscillograph (Fig. 3) driven by iron-constantan thermocouples whose resistances were calibrated with precision potentiometers. The thermocouples were located at various points

along the exhaust system. Figure 4 shows the exhaust system and the locations of the thermocouples for a typical car and how the thermocouples were attached to the pipe.

Figure 3. Instrumentation used for vehicle tests

The exhaust system pressure and intake manifold vacuum were monitored. For dynamometer runs, engine rpm was also recorded, as were air-fuel ratio and road horsepower.

No attempt was made to evaluate how effectively the air pollution control devices controlled exhaust emissions from equipped vehicles, other than to determine that the air pump was operative on those which had an air injection reactor. See Appendix, Figure 16 for illustration of this type of system. For the remainder of the report, the word "equipped" will signify "equipped with an exhaust smog control device" and "unequipped" will signify that the vehicle does not have any type of exhaust emission's control device.

Each vehicle was tested as received. Then ignition timing, idle rpm, point dwell, and distributor advance were measured and compared with the manufacturer's specifications. If the vehicle was not within specifications, it was corrected and then retested.

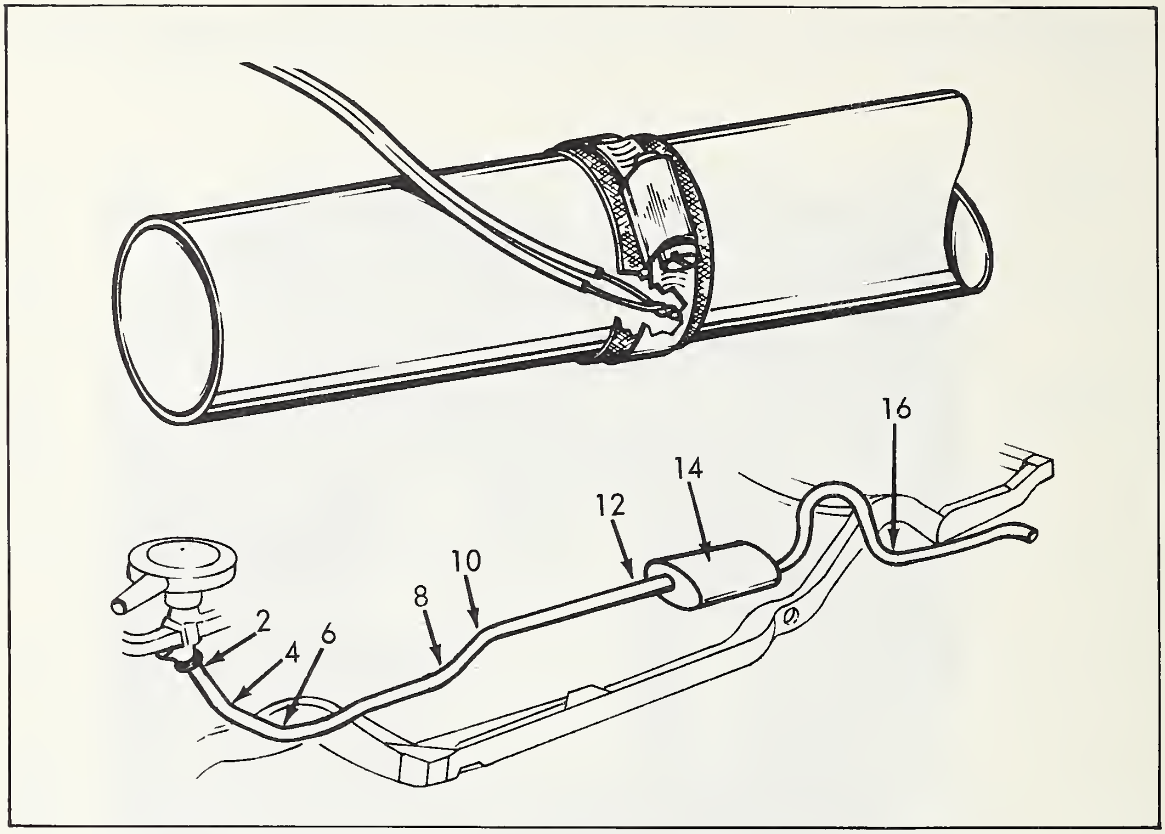


Figure 4. Method of attaching thermocouple to exhaust pipe (above); Thermocouple station locations for a typical car (below).

Road Tests

The road course used was Mt. Baldy Road, starting at Dam 2238 and running seven miles, average grade 3 percent, nearly to Mt. Baldy Village. This road is located on the Angeles National Forest in Southern California. The starting elevation is about 2,000 feet, the elevation at the end of the test run is about 3,500 feet, and the grade of the section used to obtain maximum temperatures is about 7-1/2 percent.

This test course was long enough to insure that starting exhaust system temperatures did not affect final results. The standard road test applied to each vehicle was a second-gear, 40-mile-per-hour, constant-speed run. Other gear-speed combinations were tried, but this was found to be the most easily repeatable type of run which produced maximum temperatures. Also, earlier work (Ref. 2) had shown that, for road conditions, the maximum exhaust temperatures are developed at approximately 40 miles per hour with the vehicle in one gear lower than its direct-drive gear; e.g., second gear for a three-speed manual transmission, third for a four-speed. No vehicles with automatic transmissions were tested. Forty miles per hour, in one gear lower than high, was found through dynamometer tests to correspond very nearly to the engine rpm which gave maximum horsepower for all the vehicles tested. For road tests, each vehicle was loaded with sandbags, instruments, and operators to its maximum permissible on-pavement payload.

Dynamometer Test

The dynamometer test consisted of two parts. The first was a group of steady-load tests, in which exhaust system temperature was allowed to come to equilibrium. This condition revealed the maximum temperature which the exhaust system would achieve under heavy load. The second consisted of a cyclic driving test, the so-called California 7-mode cycle. This involved "driving" the vehicle on the dynamometer through seven repetitions of the dynamometer cycle devised by the California Motor Vehicle Pollution Control Board for testing smog control devices (Ref. 6). This was done to obtain results which would be directly comparable to exhaust system temperature data obtained by using the California 7-mode cycle, available from the U.S. Public Health Service.

Cooling during dynamometer runs was provided by a Chelsea PLDUP 300A fan (see Fig. 5). Figure 6 shows the axial wind velocity distribution obtained two inches beneath the bottom of the car. The illustration indicates that the wind velocity due to the Chelsea fan is approximately seven miles per hour. Tests were made with the engine running.

Figure 5. Test car in place on chassis dynamometer

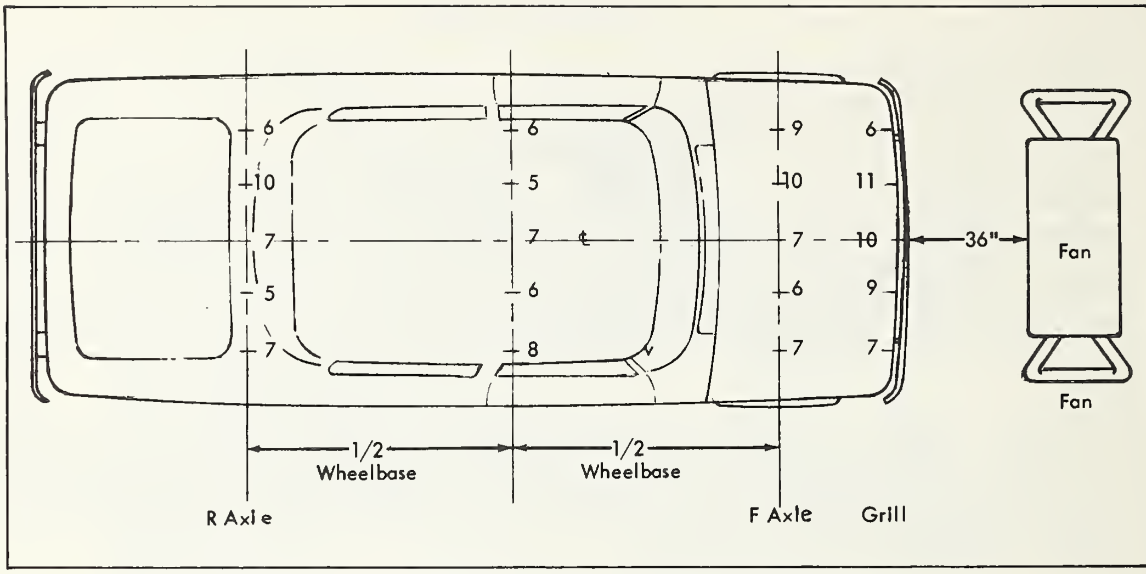


Figure 6. Under-car wind velocity distribution.
Figures indicate local velocity in miles per hour.

For dynamometer steady-load tests, the same rpm gear-combination was used; 40 miles per hour, second gear. Wide-open throttle was employed to achieve maximum horsepower conditions. Runs were also made at the manifold vacuum obtained during the road test.

Typical Data

Figure 7 shows typical dynamometer test data. Note how the exhaust system temperatures level off before the final portion of the run. Figure 8 summarizes data from a typical road test run. The peak temperatures occur near the top of the 7-1/2 percent grade test section. The declining temperatures result from a short downhill "cool-down" section. The peaks are read as the test temperature.

TEST RESULTS, FOREST SERVICE FLEET

Figures 9, 10, and 11 show the temperature distributions for all three makes of vehicles along the exhaust pipe. Table 2 summarizes the results shown in these figures by comparing "first bend" temperatures for all groups with ("equipped") and without ("unequipped") smog devices. The most important temperature of the exhaust system is that of the "first bend", defined as the hottest point on the exhaust pipe which is likely to come into contact with ground cover fuels. This corresponds to Station 6, shown in Figure 4. Plymouth's first bend temperatures (Fig. 9) are higher than the temperatures encountered anywhere else on the exhaust system, even higher than at the manifold exhaust pipe joint. This is probably because cooling air from the fan does not reach the first bend area, while, because of the design of the Plymouth engine compartment, the first 40 inches or so of the exhaust pipe are effectively cooled by the fan.

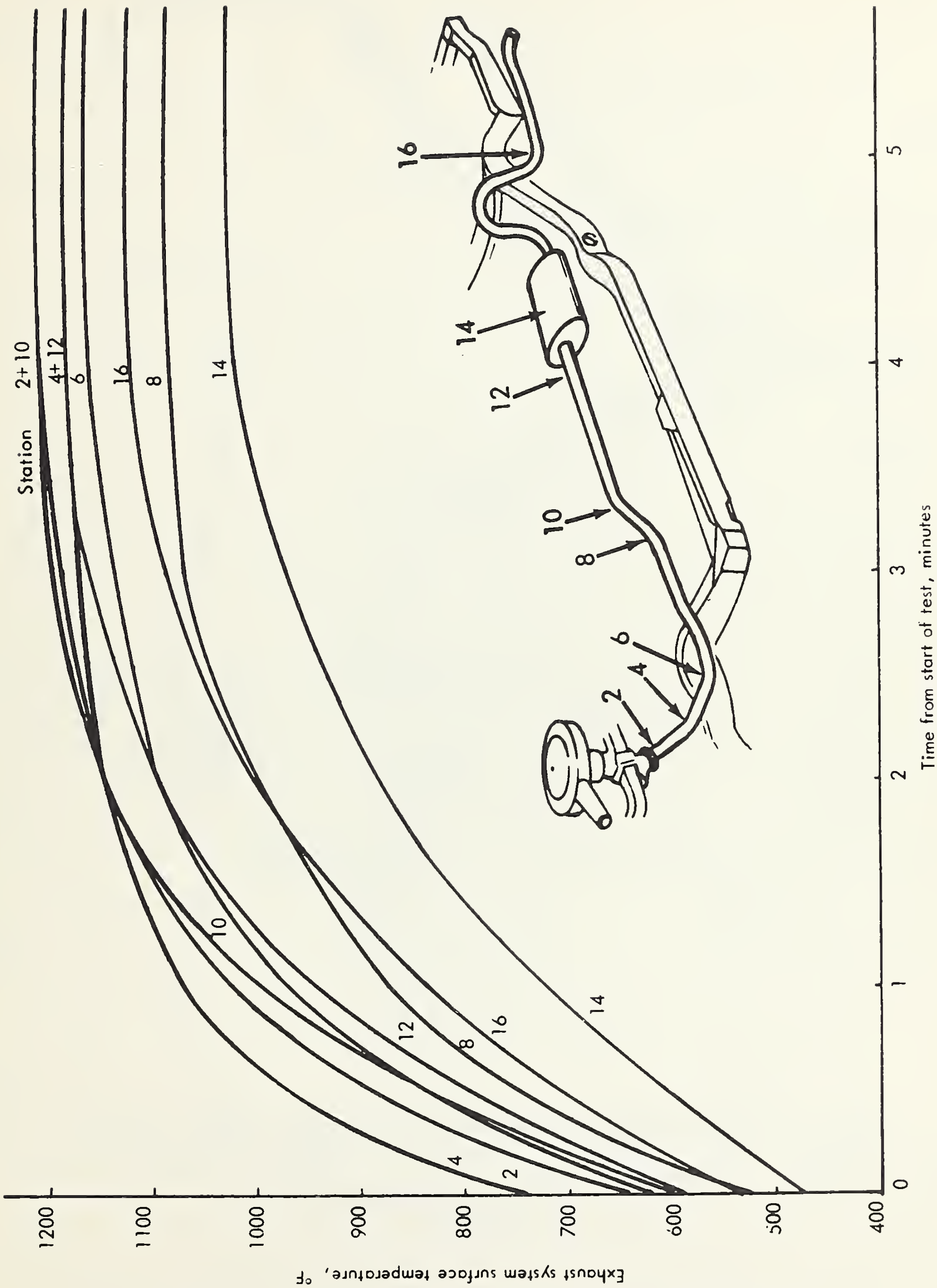


Figure 7. Typical dynamometer test data; Insert shows thermocouple station locations.

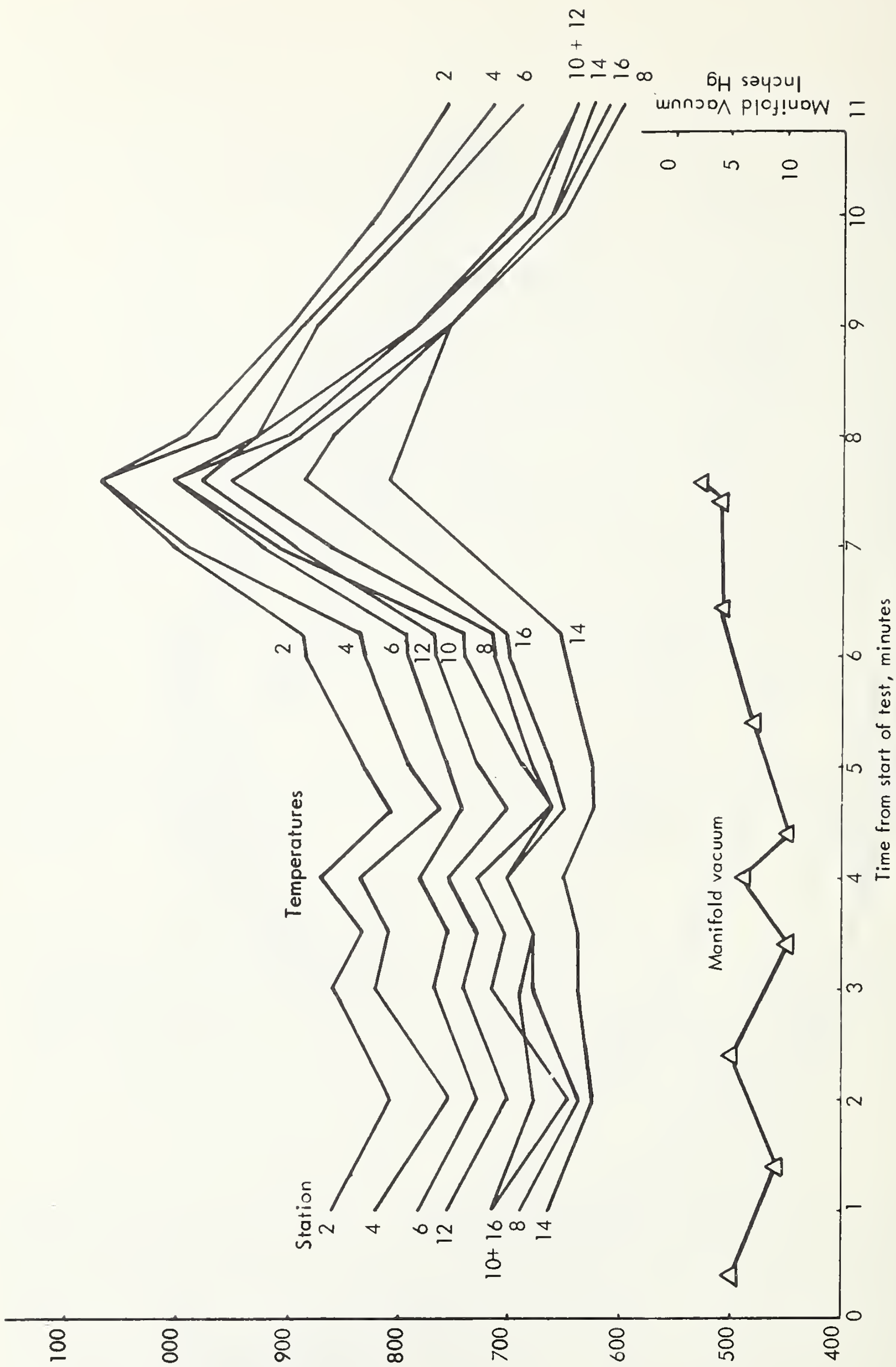


Figure 8. Typical road test data

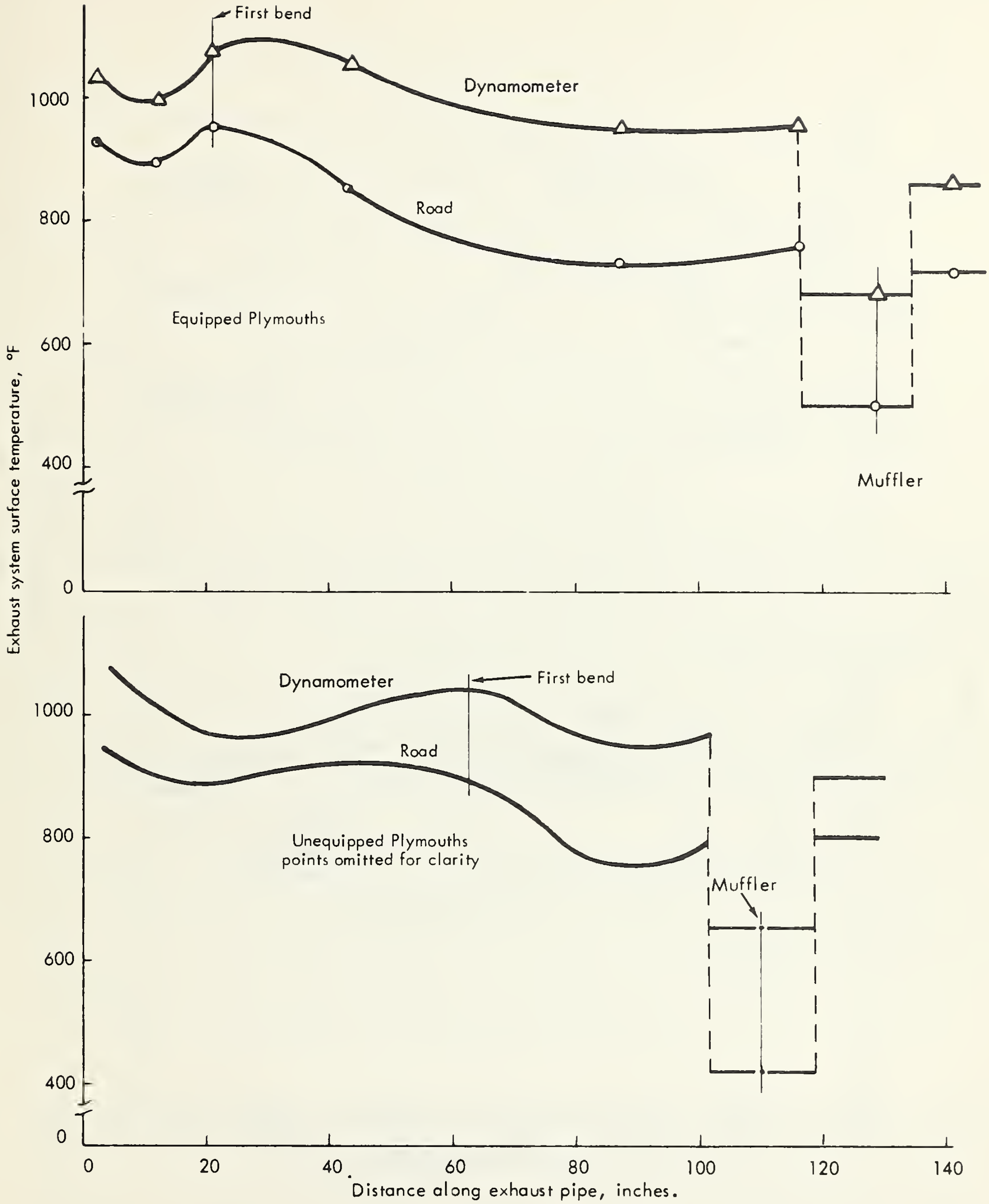


Figure 9. Exhaust pipe surface temperature distribution, Plymouths

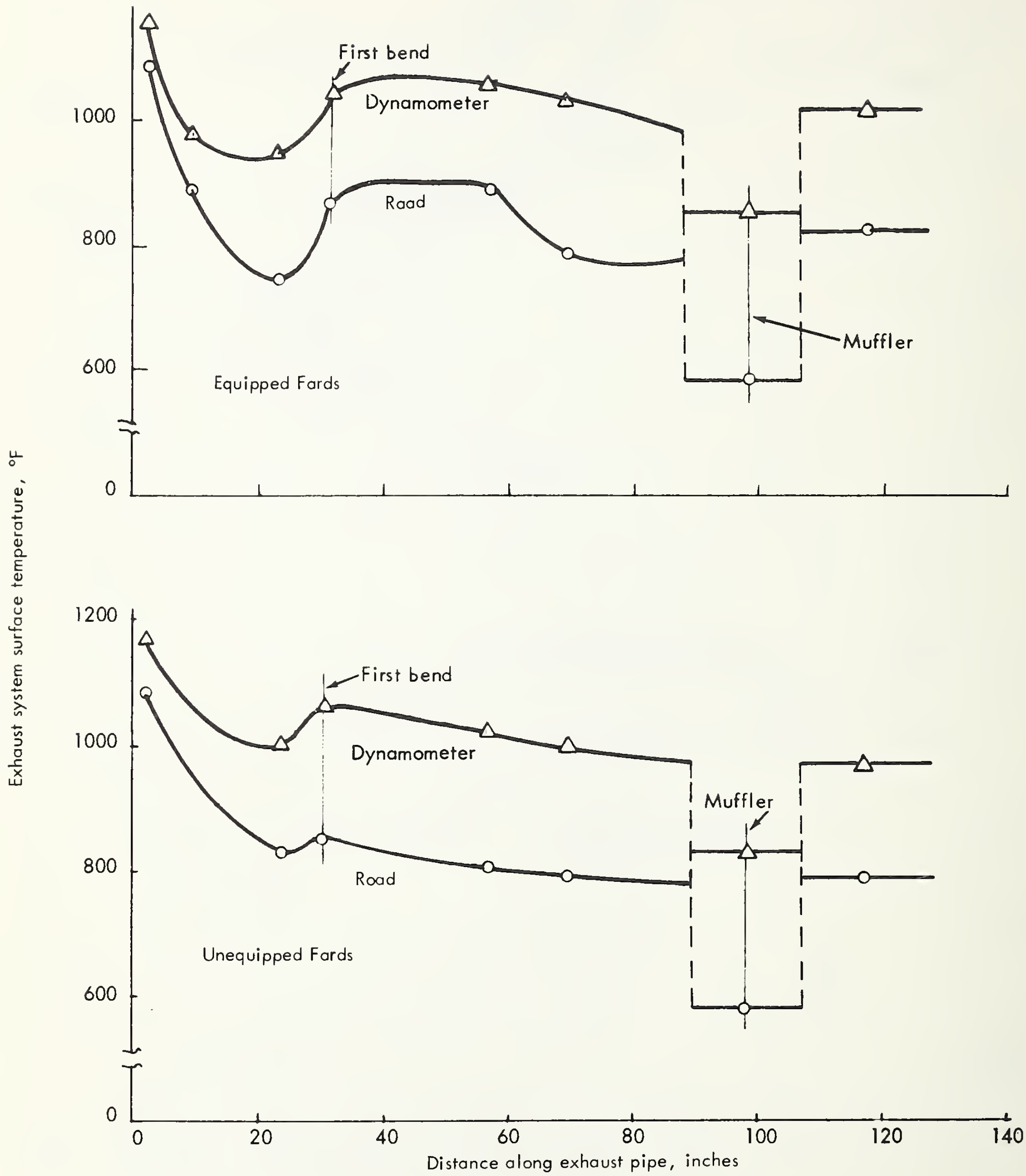


Figure 10. Exhaust pipe surface temperature distribution, Fords

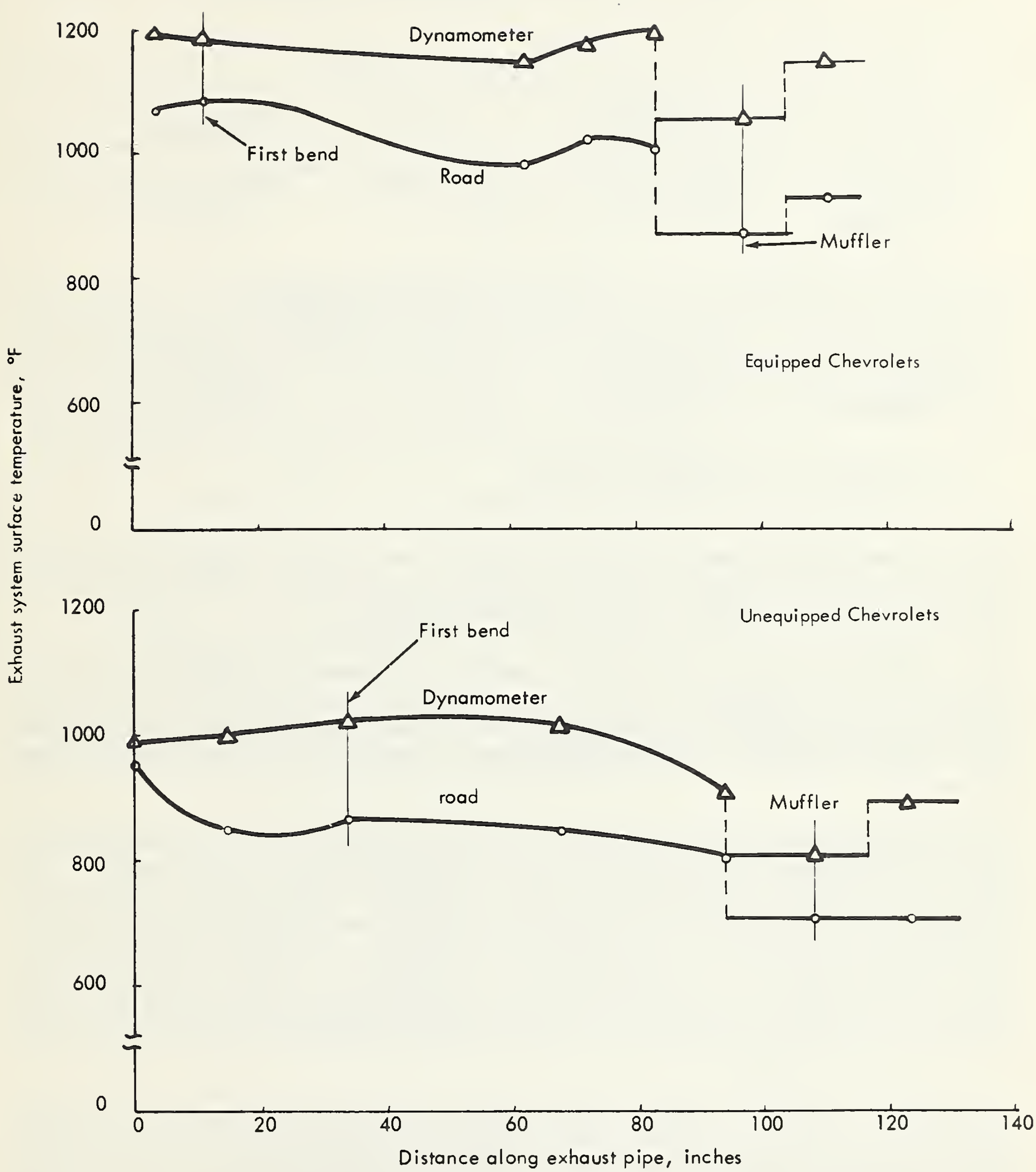


Figure 11. Exhaust pipe surface temperature distribution, Chevrolets

Table 2. First bend temperatures, all groups
(The ± figures represent the 90% confidence interval)

	ROAD TESTS		
	PLYMOUTH	FORD	CHEVROLET
Equipped	954 ± 30° F	873 ± 16° F	1080 ± 71° F
Unequipped	947 ± 52° F	855° F*	849 ± 65° F
	DYNAMOMETER TESTS		
Equipped	1080 ± 25° F	1050 ± 17° F	1210 ± 25° F
Unequipped	1070 ± 48° F	1062° F*	1002 ± 79° F

*1-car group, no confidence interval

It can be seen from Figure 11 that for Chevrolets the exhaust temperatures are approximately 200° F higher for equipped vehicles than for those without smog control devices. This corroborates work previously done (Ref. 4).

Note from Table 2 that the Plymouths exhibit no temperature difference between equipped and unequipped cars. This is to be expected, since the Chrysler Corporation employs an induction device, as opposed to the manifold air oxidation system used by Chevrolet and Ford. (See Appendix for a description of each exhaust control system.)

The Ford group results do not agree with previous tests (Ref. 2). The temperatures for the unequipped cars are not significantly different from those of equipped cars (Fig. 10) even though the Ford Motor Company employs manifold air oxidation. The discrepancies between the Ford results and those of the Chevrolets are difficult to explain. Variations between equipped and unequipped Chevrolet engine parameters alone could account for no more than 50° F difference. Perhaps oxidation of the Chevrolet engine's unburned hydrocarbons in the exhaust manifold is the cause. If this were the case, the Ford groups should exhibit differences similar to those seen in the Chevrolet groups.

Statistically, too much weight should not be attached to the results of the Ford groups since only two equipped vehicles and one unequipped vehicle were available. Original plans included two 1961 Fords in the unequipped group and these vehicles were tested; but they are so dissimilar to the equipped group in engine and exhaust system configuration that the results were not applicable.

The correlation is excellent between dynamometer tests and road runs for all three groups. The dynamometer test results average approximately 150° F hotter than the road runs.

The results of both dynamometer and road tests run before and after tuneup, when required, showed no significant differences.

It had been suggested (Ref. 5) that the removal of one spark plug wire on an air-injection-equipped car could lead to very high exhaust system temperatures when the car is decelerated (under such conditions as might be encountered going down a long hill). This would be caused by the unburned fuel-air charge (resulting from the failure of the one cylinder to fire) burning in the exhaust system. Several Fords and Chevrolets were decelerated down the Lower Baldy road course both with and without one spark plug wire disconnected. No significant difference in temperatures was noted.

Figure 12 shows first bend cooling as a function of time for the Plymouths and Chevrolets. These temperatures were obtained immediately after parking the test vehicles after a road test run. Because of the limited number available, the Fords are omitted. The data from these groups, however, follow the same general pattern shown in Figure 12. Whether the engine was idling or dead made no significant difference, so each curve is an average of runs both with and without the engine idling. The cooling curve is approximately described by the equations:

$T = T_0 - 188t^{0.61}$ where t is between 0 and 5 minutes

$T = T_5 - 18t$ where t is between 5 and 10 minutes

Where T = the temperature of any given time, °F; T_0 = the maximum or starting (0 - time) temperature; T_5 = the temperature at 5 minutes; and t = the time in minutes

This equation has been empirically derived from the data shown in Figure 10 and appears to be reliable for the range of values encountered during this study. The application of this equation yields conservative results.

In order to determine the correlation between road test first bend temperatures and temperatures reached in actual service, a "telltale" temperature indicator was attached to the first bend before the vehicle was returned to service. After 30 driving days the indicator was returned to San Dimas by the vehicle operator. Each driver was asked to fill out a brief vehicle history report each day to determine if the vehicle had been subjected to unusual conditions. The indicator is accurate within $\pm$ 1 percent of the indicated temperature; the temperature increments are 50° F. Normal in-service temperatures, as obtained by the telltales, averaged 125° F lower than the Lower Baldy road test temperatures for each car.

When the Equipment Development Center's 7-mode data (Ref. 6) are compared to similar data obtained by the U. S. Public Health Service, excellent agreement is seen (Ref. 3). The 7-mode test yields maximum temperatures much lower than those obtained during dynamometer and road tests. This indicates that the 7-mode procedure, as used by both the State of California (Ref. 6) and the USPHS to test smog device effectiveness, is not applicable to exhaust system temperature testing.

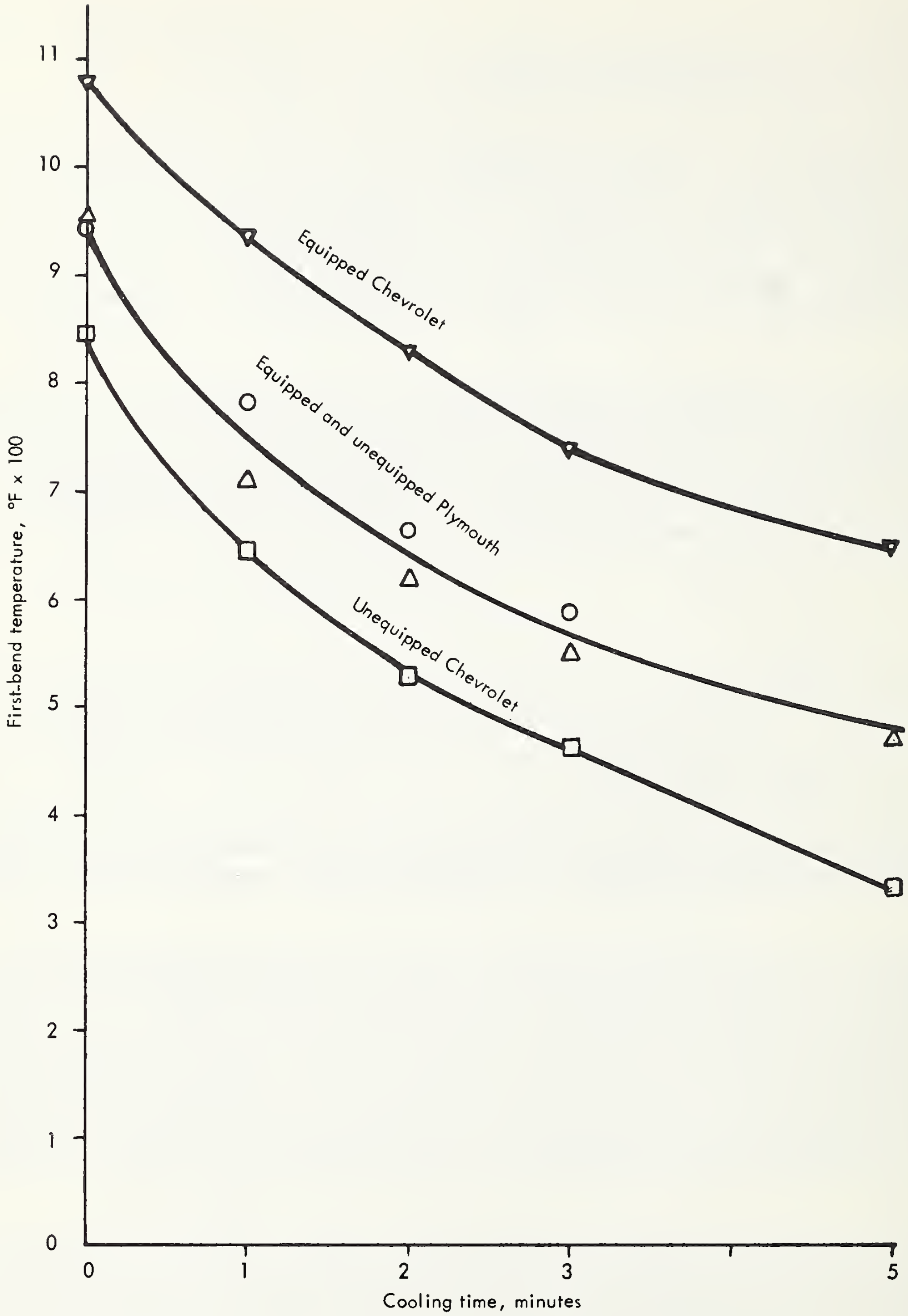


Figure 12. First bend cooling time for Chevrolet and Plymouth groups

TEST METHODS, LATE MODEL FLEET

Two new 1968 Chevrolet pickup trucks with 292-cubic inch engines and 4-speed manual transmissions were selected for test. This model was chosen because Northern Region engineers had obtained exhaust system temperatures from a similar truck. The vehicles were instrumented by attaching an iron-constantan thermocouple to the outside of the first bend of the exhaust pipe. Also, an iron-constantan thermocouple was inserted 1/2 inch into the gas stream at the first bend. This was the method used by the Northern Region engineers. The temperatures were read using a vacuum tube voltmeter powered by a portable generator. The accuracy of the system was found to be approximately plus or minus 1 millivolt (plus or minus 30° F).

The trucks were tested in the same manner and over the same road course as used for the fleet test. In addition, constant speed level road tests were run to correlate EDC data with that obtained by the Northern Region engineers who used this procedure.

TEST RESULTS, LATE MODEL FLEET

Table 3 below lists the test modes utilized and the results of the tests. Each vehicle was run through each mode at least once with the AIR (Air Injection Reactor) pump both connected and disconnected.

From the test data presented in Table 3, the following is obvious:

1. The surface temperature at the first bend of a Chevrolet 292-cubic-inch pickup truck will be approximately 100° lower than the gas temperature at the same location.

2. The first bend temperature of an AIR-equipped Chevrolet pickup will be hotter than that of a non-equipped pickup by a factor of approximately 1.3 for the Mt. Baldy test condition.

3. The 1968 Chevrolet trucks are approximately 250° hotter than the earlier model pickup trucks tested.

The Northern Region data for the truck equipped with AIR is surprisingly high. At present, there is no explanation for the discrepancy.

FUTURE DIRECTION OF EXHAUST SYSTEMS TEMPERATURES

The question could now be asked, "How hot are the exhaust systems of 1969 cars, and how hot are exhaust systems of subsequent year model cars likely to be?"

Information obtained from Miles Brubacher, Supervising Engineer of the California Air Resources Board, the agency charged with California's automobile smog program, revealed that car manufacturers are phasing out, as fast as possible, the AIR emission controls in favor of engine modifications. Although it is possible that the more stringent exhaust standards, which will come into effect nationwide in 1970, might require air pump controls, Mr. Brubacher feels that, in the foreseeable future,

Table 3. Chevrolet pickups, summary of data

Surface temperatures ° F

Mode of Operation	Average of 2 1968 Trucks		3 1966 F.S. Trucks		Difference 1st col. minus 2nd col.	
	With AIR	Without AIR	With AIR	Without AIR	With AIR	Without AIR
Idle	710	535	-	-	-	-
20 mph level road	750	575	-	-	-	-
40 mph level road	845	675	-	-	-	-
60 mph level road	1070	920	-	-	-	-
Climb 2 mi. 7% grade, 40 mph 3rd gear (Baldy Course)*	1325	1065	1080	840	245	215
1 min. idle after above test*	1185	810	930	640	255	170
2 min. idle after above test*	1130	740	820	525	310	215

Gas temperatures ° F

Mode of Operation	Average of 2 1968 Trucks		R-1 Report 1 1968 Truck		Difference 1st col. minus 2nd col.	
	With AIR	Without AIR	With AIR	Without AIR	With AIR	Without AIR
Idle	835	730	1405	520	570	210 cooler
20 mph level road	820	795	1225	710	405	85 cooler
40 mph level road	950	985	1085	1030	135	45 hotter
60 mph level road	1180	1150	1395	1350	215	200 hotter
Climb 2 mi. 7% grade, 40 mph 3rd gear (Baldy Course)*	1440	1230	-	-	-	-
1 min. idle after above test*	1235	850	1415	890	180	40 hotter
2 min. idle after above test*	1195	795	1415	805	220	10 hotter

All modes except those with * show equilibrium temperatures.

engine modifications will be the main method of controlling exhaust emissions. An estimated 80 percent or more of 1969 model or later American vehicles and an estimated 80 percent of 1969 model or later foreign vehicles have or will have engine modification control. Table 4 shows which type of device is fitted to each make of 1969 automobile sold in the United States.

Table 4. Exhaust emission control systems fitted to 1969 automobiles

AMERICAN VEHICLES

Manufacturer	Type	Models Fitted
American Motors Corp.	AIR*	8 cylinders with manual transmission
	EM**	All 6 cylinder engines 8 cylinders with automatic transmission
Checker Motors Corp.	AIR	Aerobus and all vehicles with manual transmission
	EM	Vehicles with automatic transmission, except Aerobus
Chrysler Corp.	EM	All
Ford Motor Company	AIR	302 (2 - 4 bbl. carburetors); 427, 428 and 429 (4 bbl. carburetor) cu. in. engines
	EM	All except high performance engines (see AIR)
General Motors Corp.	AIR	Cadillac Chevrolet: all vehicles with manual transmissions All Corvairs and Corvettes All trucks and vans (except El Camino) All 396 cu. in. engines with 4 bbl. carburetors and open element air cleaners All 427 cu. in. engines (except full size Chevrolet cars with Rochester carburetors) GMC: all 230, 250, 292 and 396 cu. in. engines - 307 and 350 cu. in. engines with manual transmission
	EM	All Buicks, Pontiacs and Oldsmobiles Chevrolet: vehicles with automatic transmission except as listed in (AIR)

*AIR - Air Injection System

**EM - Engine Modification System

Table 4 (cont'd.)

Manufacturer	Type	Models Fitted
General Motors Corp.	EM	GMC: 305, 351, 401, 478 and 637 cu. in. engines; 307 and 350 cu. in. engines with automatic transmission
International Harvester	EM	All
Kaiser Jeep Corp.	AIR	4 and 6 cylinder engines
	EM	8 cylinder engines
Shelby	AIR	GT-500 (428 cubic inch engine)
	EM	GT-350 (351 cubic inch engine)
White Motor Corp.	EM	Diamond-Reo 6 cylinder engines

FOREIGN VEHICLES

Manufacturer	Type	Models Fitted
Adam-Opel	AIR EM	Both systems approved for 65.8 and 115.8 cu. in. engines
Alfa Romeo	EM	108.6 cu. in. engine
Aston Martin Lagonda	EM	244 cu. in. engine
Bayerische Motoren Werke (BMW)	AIR	96 and 121 cu. in. engines
British Motor Corp.	AIR	77.9, 109.8, and 177.8 cu. in. engines
Citroen	AIR	121 and 132 cu. in. engines
Daimler-Benz (Mercedes)	AIR	139.6, 152.3, and 169.4 cu. in. engines
	EM	134, 169.4, and 386 cu. in. engines
English Ford	AIR	97.7 cu. in. engines
Fiat	EM	73.0 and 87.8 cu. in. engines
Jaguar	EM	258.4 cu. in. engine
Nissan Motor Co. (Datsun)	AIR	All except pickup trucks and 4-wheel-drive vehicles (97.3, 97.4, 120.9 cu. in. engines)

Table 4 (cont'd.)

Manufacturer	Type	Models Fitted
Nissan Motor Co. (Datsun)	EM	Pickup trucks and 4-wheel-drive vehicles (79.3 and 242 cu. in. engines)
NSU	EM	60.8 and 71.8 cu. in. engines
Peuguot	EM	98.8 cu. in. engines
Porsche	EM	96.5 and 121.5 cu. in. engines
Renault	EM	67.6 and 95.5 cu. in. engines
Rolls-Royce	AIR	380.2 cu. in. engine
Rover Company (Rover & Land Rover)	EM	120.8 and 139.5 cu. in. engines
SAAB	EM	91.4 cu. in. engine
Simca	EM	68 and 73 cu. in. engine
Standard-Triumph Co.	EM	79, 122, and 152 cu. in. engines
Toyo Kogyo (Mazda)	AIR	90.97 cu. in. engine
Toyota	AIR	65.8, 113.4, 115.8, 137.1 and 236.7 cu. in. engines
	EM	113.4 and 236.7 cu. in. engines
Vauxhall	AIR	70.7, 97.5 and 120.5 cu. in.
Volkswagen	EM	All
Volvo	EM	121 cu. in. engine

To establish the effects of these more recent engine modification control systems on exhaust temperatures, the Equipment Development Center tested eight 1969 model automobiles equipped with engine modification exhaust system controls. The types of cars tested and the results obtained from Mt. Baldy course road tests are shown in Table 5.

Table 5. Comparison of road test results

(All cars equipped with exhaust emission controls)

	1966-'67 Models	1968 Models	1969 Models
Chrysler Products:			
Number & type tested	4 sedan deliveries, 6-cyl., manual trans.	-	2 sedans, V-8, automatic
Peak first bend temperature, average of cars tested	954° F $\pm$ 30° F (EM)	-	948° F $\pm$ 85° F (EM)
Ford Products:			
Number & type tested	2 sedans, 6-cyl., manual trans.	-	2 sedans, V-8, automatic
Peak first bend temperature, average of cars tested	873° F $\pm$ 16° F (AIR)	-	856° F $\pm$ 52° F (EM)
Chevrolet Products:			
Number & type tested	3 pickups, 6-cyl., manual trans.	2 pickups, 6 cyl., manual trans.	3 sedans, V-8, automatic
Peak first bend temperature, average of cars tested	1080° F $\pm$ 71° F (AIR)	1325° F $\pm$ 79° F (AIR)	972° F $\pm$ 35° F (EM)

In addition to the above-mentioned American cars, one foreign car, a 1969 Datsun 4-door sedan, was tested. This vehicle has a 96-horsepower, 4-cylinder, overhead cam engine of 1600 cc and a 4-speed manual transmission. It differs from the 1969 American cars tested in that its air pollution control device does employ an air pump. The peak first bend temperature achieved on the Mt. Baldy road test was approximately 1090° F, or very nearly the same as the peak temperatures achieved for 1966 Chevrolet 6-cylinder trucks equipped with air pumps (see Table 2) and significantly cooler than the 1968 Chevrolet pickup trucks tested.

PHASE III - PARAMETER STUDIES

The engine parameters likely to cause a variation in exhaust system temperatures are ignition timing, exhaust system back pressure, and air-fuel ratio. Operational parameters which could affect exhaust temperature are wind speed (vector sum of vehicle velocity and ambient wind), load, engine rpm, and fuel-knock rating.

Ambient conditions to consider are temperature, relative humidity, barometric pressure, and grade and safe driving speed of the road used. All parameter studies were conducted on a 1961 Ford 6-cylinder sedan (FS 75).

Although only one parameter at a time was changed during the tests, the effect of two or more simultaneous changes would be additive for the limited range of variations studied.

IGNITION TIMING

Figure 13 shows the effect of varying the ignition timing on first bend temperature for one car. At speeds over about 2,500 rpm, the ignition timing is similar for similar engines, whether or not they are equipped with smog devices, even though the basic (idle-speed) timing and distributor curves are different (Ref. 11).

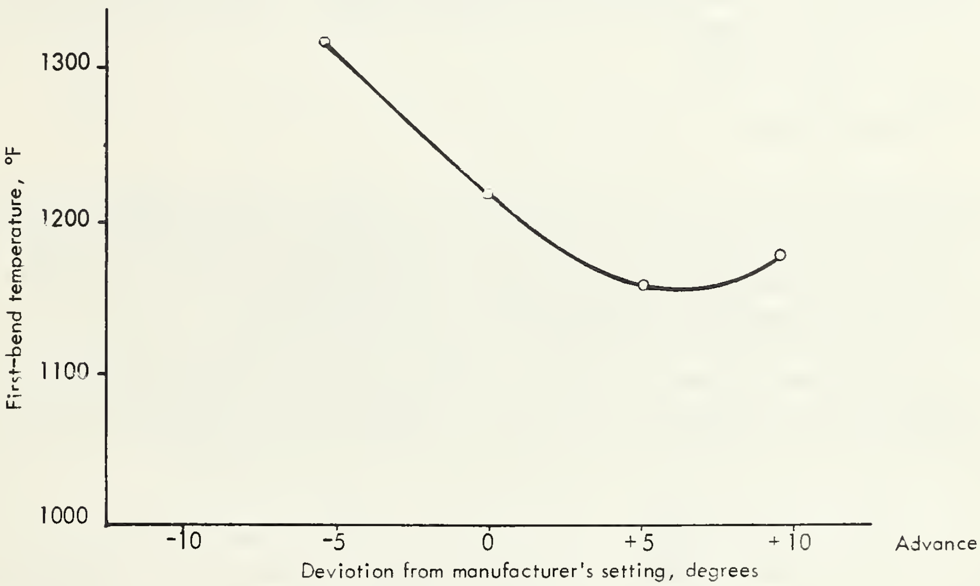


Figure 13. First bend temperature as a function of ignition timing

EXHAUST BACK PRESSURE

Varying the exhaust system pressure while maintaining horsepower output at a constant level caused the dynamometer-run maximum horsepower first bend temperature to vary 5° F per psi increase in pressure. The test data are in good agreement with those of others (Ref. 10).

For the equipped Chevrolet fleet, the exhaust pressure averaged 3.5 psi. The unequipped fleet averaged 2.4 psi. This difference in exhaust pressures could account for, at most, only a 10° F exhaust temperature difference. It is interesting to note that the cracking pressures for the air pump relief valves on the Fords and Chevrolets were experimentally found to be the same - about 2/3 psi, or considerably less than the pressures encountered in the exhaust systems of unequipped cars under full-throttle conditions. Thus it can be seen that exhaust pressure is not increased by the smog control device pump. Other exhaust system changes, such as muffler design, system configuration, etc., are no doubt responsible for the small pressure increase shown over unequipped Chevrolets by equipped Chevrolets.

FUEL-AIR RATIO

No empirical studies were made of the effect of changing fuel-air ratio on exhaust system temperature. However, calculations show that changing the relative fuel-air ratio (mass ratio of fuel to dry air divided by stoichiometric mass fuel air ratio) from 1.3 (the richest mixture encountered in any equipped Chevrolet tested) to 1.0 (where the hottest exhaust system temperatures occur) would increase mean gas temperature only 30° F (Ref. 9, Chapter 4). This would result in a first bend temperature increase of only about 25° F.

FUEL KNOCK RATING

Normally encountered variations in fuel octane rating, heat content, etc., would not be expected to affect exhaust system temperatures. An exception could occur when a vehicle engine operates normally on premium grade fuel and knocks on regular. This is an academic point, because an engine knocking badly enough to raise exhaust temperatures significantly would soon be destroyed.

One set of maximum horsepower runs was made using regular and premium fuels in a vehicle which did not knock on regular. No significant temperature differences were noted.

ENGINE SPEED AND LOAD

Maximum exhaust system temperatures were measured at maximum horsepower output, since both heat-rejection rate and exhaust flow are greatest at this point. It is possible that engine speeds higher than the maximum horsepower rpm could cause higher exhaust system temperatures. This point is of little practical importance, however. In normal use it is neither practical nor advisable to operate in this region. Figure 14 shows the effect of intake manifold vacuum on exhaust system temperature. All runs were made at 3,800 rpm. The figures adjacent to the data points indicate dynamometer horsepower. Figure 15 gives the temperature variation as a function of engine speed. The effect of road speed is shown on the same graph. Note that no significant temperature increase occurs after about 40 mph (second gear), which corresponds quite nearly to the manufacturer's rated maximum horsepower engine speed for the test car (4,000 rpm).

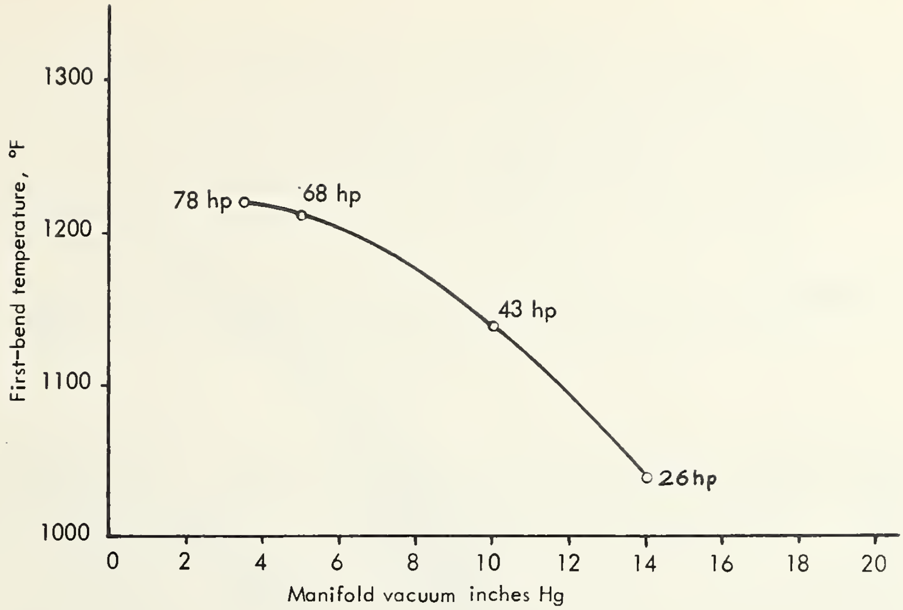


Figure 14. First bend temperature as a function of engine load

COOLING EFFECT OF WIND

Little is known of the effect of wind velocity on hot surface sooling at low wind speeds. Theoretical predictions fail to adequately describe actual situations for such complex shapes as automotive exhaust systems. There are no roads in the San Dimas area that permit steady-state testing until equilibrium exhaust system temperature is reached; therefore, road and dynamometer test results are not necessarily comparable. A comparison was made between the cooling rate of a vehicle exhaust system, with the vehicle standing, engine idling, and a similar vehicle coasting at a constant 40 mph, engine idling. No significant difference was noted. Thus, at least at speeds of less than 40 mph, under-vehicle cooling is not greatly affected by vehicle speed.

AMBIENT CONDITIONS

No attempt to control ambient conditions was made during either road or dynamometer tests. No correlation was seen to exist between either atmospheric temperature or relative humidity and exhaust system temperature for the entire fleet, because of the width of variation in temperatures between individuals in the fleet.

Ambient air temperature would be expected to have a direct effect on exhaust system temperature, for several reasons. First, the under-hood temperature (carburetor inlet temperature) is affected. Second, coolant temperature is higher on a hotter day. Third, the temperature of the heat sink (the area surrounding the exhaust system) is directly related to ambient temperature. Also, the density (thus the mass flow rate) of carburetor inlet air will be affected by both atmospheric pressure and temperature.

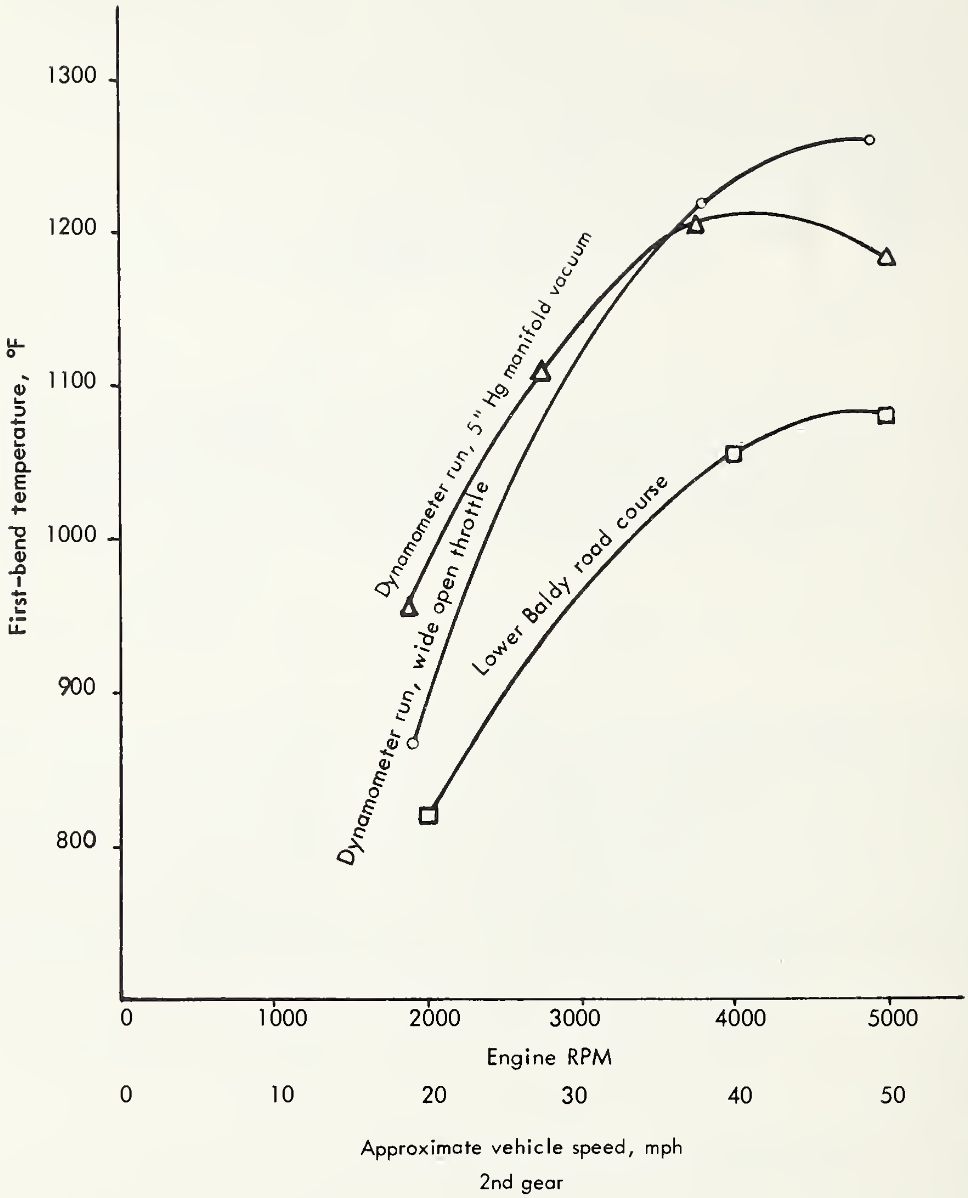


Figure 15. First bend temperature as a function of engine speed

Theoretical calculations, based on the fuel-air cycle, indicate a rise in end gas temperature (cylinder gas temperature at the end of the exhaust stroke) of about 2° F per 1° F increase in inlet temperature (Ref. 9, chapter 4). The relationship between calculated end gas temperature and first bend temperature for the fleet tested is about 2 to 1. Thus, a rise in first bend temperature of about 1 degree for each degree increase in ambient temperature could logically be expected.

Relative humidity and barometric pressure variations in the range encountered in practice would not be expected to cause major variations in exhaust system temperatures.

ROAD CONDITIONS

One car was driven on several road courses to determine the effect of road grade and driving speed on peak first bend temperature. The results are shown in Table 6. The hottest temperatures were obtained on the Lower Baldy course, even though equilibrium temperatures were not reached. This points out the need for sustained low manifold pressures (high throttle openings) to achieve maximum temperatures. Also, relatively low temperatures were obtained on the Forest Service Land Utilization Road.

Table 6. Effect of road type on maximum first bend temperature

1961 Ford, unequipped
Ambient temperature 75-92° F

Description of Course	Avg. Grade	Road Test Avg. Manifold Vac. In. Hg.	Throttle Opening Steady	Gear Used	Avg. Speed	Max. First Bend Temp. Achieved °F
Lower Baldy course - described in text	+7½%	5	Yes	2nd	40 mph	1140
Freeway straight and constant	+4%	15	Yes	3rd	65 mph	970
Around town driving	0	15	No	2nd, 3rd	35 mph	677
Country road, mountainous terrain	+8%	17.5	No	2nd, 3rd	30 mph	930
Forest Service L.U. road	+9-11%	15	No	1st	15 mph	803

ACCURACY OF RESULTS

Table 2 shows average first bend temperatures for each group in the Forest Service test fleet, for both equipped and unequipped vehicles. The maximum 90 percent confidence interval shown is ± 79° F, with the average being approximately ± 50° F. This means that 9 out of 10 vehicles in the group described will have an exhaust system temperature within the range shown. No more than 1 in 20 would be expected to exhibit a first bend temperature hotter than this range. This assumes that all vehicles are tuned to manufacturer's specifications and that engines are in reasonable repair. These are remarkably consistent data, considering that no attempt was made to control ambient atmospheric conditions.

The resolution of the temperature readout is approximately 15° F. The oscillograph-thermocouple system was calibrated against the freezing points of lead, aluminum, and sulfur and the boiling point of water and was found to be within the 15° F resolution. Zero points and thermocouple trim resistances were checked between vehicle tests and reset if necessary. No calibration shift of over 5° F was noted.

The reliability of the data for 1968 and 1969 models is comparable to that obtained in the Forest Service Fleet test. The variation, plus or minus degrees Fahrenheit, shown with the average temperatures in the table is the 90 percent confidence interval.

The results shown for 1960 through 1966 Chevrolet 6-cylinder pickups are in excellent agreement (within 10 percent) with the study conducted by a special committee of the Automobile Manufacturers Association at Redding, Calif., on September 20, 1966 (Ref. 4).

CONCLUSIONS

1. Under actual operating conditions, the exhaust system temperatures of 1960-66 Forest Service sedans and pickups reach nearly 1,000° F for vehicles not equipped with exhaust control devices and average 1,080° F for certain smog-device-equipped models. At several locations along the exhaust pipe, temperatures exceeded 650° F, the assumed minimum ignition temperature of ground cover fuels. The maximum exhaust system temperature is reached after sustained operation (7 minutes) at high load and engine speed, under such conditions as would be encountered climbing a long grade or operating a tanker equipped with a power-takeoff-driven pump.

2. Isolated exhaust system first bend temperature excursions to over 1,080° F are likely only in certain vehicles, namely, 1968-69 Chevrolet 6-cylinder pickups equipped with AIR. This should constitute no more than 20 percent of the 1969 and later model year population.

3. Variations in ambient conditions affect the exhaust system temperature only slightly. Exhaust system temperature can be significantly raised by maladjusted ignition timing. Other engine parameters do not affect the exhaust system to any great extent.

RECOMMENDATIONS

Before further work is done to reduce these temperatures, detailed information is necessary regarding contact time and temperature required to cause ignition in various forest fuels.

Until such work is completed, it is suggested that all Forest Service vehicle operators be advised of the potentially dangerous situation which exists and instructed to use due caution. Operators of vehicles which run slowly or continuously in one location, such as power takeoff tankers, should be advised to wet down the areas which the vehicle exhaust system might contact.

REFERENCES

1. U.S. Forest Service, Arcadia Equipment Development Center, Report of Vehicle Exhaust Temperatures, Summer, 1952

2. U.S. Forest Service, San Dimas Equipment Development Center, Project Record, ED&T 1337, Ignition Characteristics of the Vehicle Exhaust Systems, Preliminary Report, by R. Harrison, Project Engineer, June 1966

3. Megonell, William H., Chief, Abatement Program, National Center for Air Pollution Control, letter to F. M. Burbank, San Dimas Equipment Development Center, January 30, 1967

4. U.S. Forest Service, San Dimas Equipment Development Center, Memo to the Record, by R. Harrison, "ED&T 1337 - Redding Tests", September 28, 1966

5. U.S. Forest Service, San Dimas Equipment Development Center, Memo to the Record, by R. Harrison, "ED&T 1337", March 30, 1967

6. State of California, Motor Vehicle Pollution Control Board, California Test Procedure and Criteria for Motor Vehicle Exhaust Emission Control, Revision of November 16, 1966

7. Fairbank, J. P., and Bainer, Roy, Spark Arresters for Motorized Equipment, Bulletin 577, University of California Agricultural Experiment Station, Berkeley, California, 1934

8. Wright, J. G., Forest Fire Research as Developed and Conducted by the Petawaw Forest Experiment Station, Forest Fire Research Institute, Ottawa, Ontario, Information Report FF-X-5, March, 1967

9. Taylor, C. Fayette, and Taylor, Edward S., The Internal Combustion Engine, Second Edition, International Textbook Company, Scranton, Pennsylvania, 1961

10. Lundin, et al., Correlation of Cylinder Head Temperatures and Coolant Heat Rejections of a Multi-Cylinder Liquid-Cooled Engine of 1710 Cubic Inch Displacement, NACA Report 931, 1949

11. Ritchen, Ralph, Motor's Auto Repair Manual, 29th Edition, Motor, 250 W. 55th St., New York, N. Y., 1966

12. U.S. Forest Service, San Dimas Equipment Development Center, Project Record ED&T 1337, Ignition Temperature of Ground Cover, by R. Harrison, August, 1966

APPENDIX

DESCRIPTION OF AIR POLLUTION CONTROL DEVICES

There are two types of smog control devices in use today; positive crankcase ventilation systems and exhaust control systems. Considerable confusion has arisen over the latter type. These have occasionally been erroneously dubbed "afterburners". There are presently no afterburners, per se, in production or use.

Positive crankcase ventilation systems have been installed as original equipment on all passenger cars and pickup trucks manufactured in the United States since 1963, as well as on several of the more popular foreign vehicles.

POSITIVE CRANKCASE VENTILATION

Devices similar to the positive crankcase ventilation system shown in Figure 16 are installed on all cars and pickup trucks manufactured in the United States since 1963. This system features a hose (1) leading from the crankcase through the PCV (Positive Crankcase Ventilation) valve into the intake manifold, a sealed breather cap (2A), and adapters and tubing (2B) connecting the crankcase and the filtered side of the air cleaner. Shown below is the operation of the system during adverse conditions of high speed or extreme acceleration with a worn engine, when blow-by exceeds the capacity of the PCV valve. Hose (1) handles most of the blow-by gases. Excess fumes are carried through the tube to the air cleaner and down into the engine. The sealed breather cap prevents escape of these excess fumes to the atmosphere.

EXHAUST EMISSION CONTROL

There are two varieties of exhaust emission control systems now being used on American vehicles, air injection reactor and induction. The air injection reactor system (Figure 17) used on Ford, GM, Jeep, International Harvester, and American Motors products employs an air pump which forces air into the exhaust manifold. The addition of this air causes oxidation of unburned gasoline in the exhaust stream. The pump is fitted with a relief valve to limit its output pressure. An exhaust check valve is incorporated in the system to prevent backflow of exhaust gases into the air pump when pressure in the exhaust system exceeds that of the pump output. An anti-backfire valve, controlled by intake manifold, is used to prevent backfiring during periods of sudden decrease in intake manifold pressure.

Air Injection Reactor

Figure 17 cutaway schematic shows the operating principle of the General Motors Air Injection Reactor system for exhaust emission control. Heart of the system is a belt-driven pump that sends fresh air to a point near the exhaust valves. Fresh air promotes further oxidation of hydrocarbons and carbon monoxide emerging from the cylinder, changing them to water and carbon dioxide.

Ignition timing and carburetor calibration are altered from non-device-equipped cars at low rpm and load; but the distributor and carburetor are so arranged that, at full-load conditions, ignition timing and air-fuel ratio are nearly identical for equipped and unequipped cars.

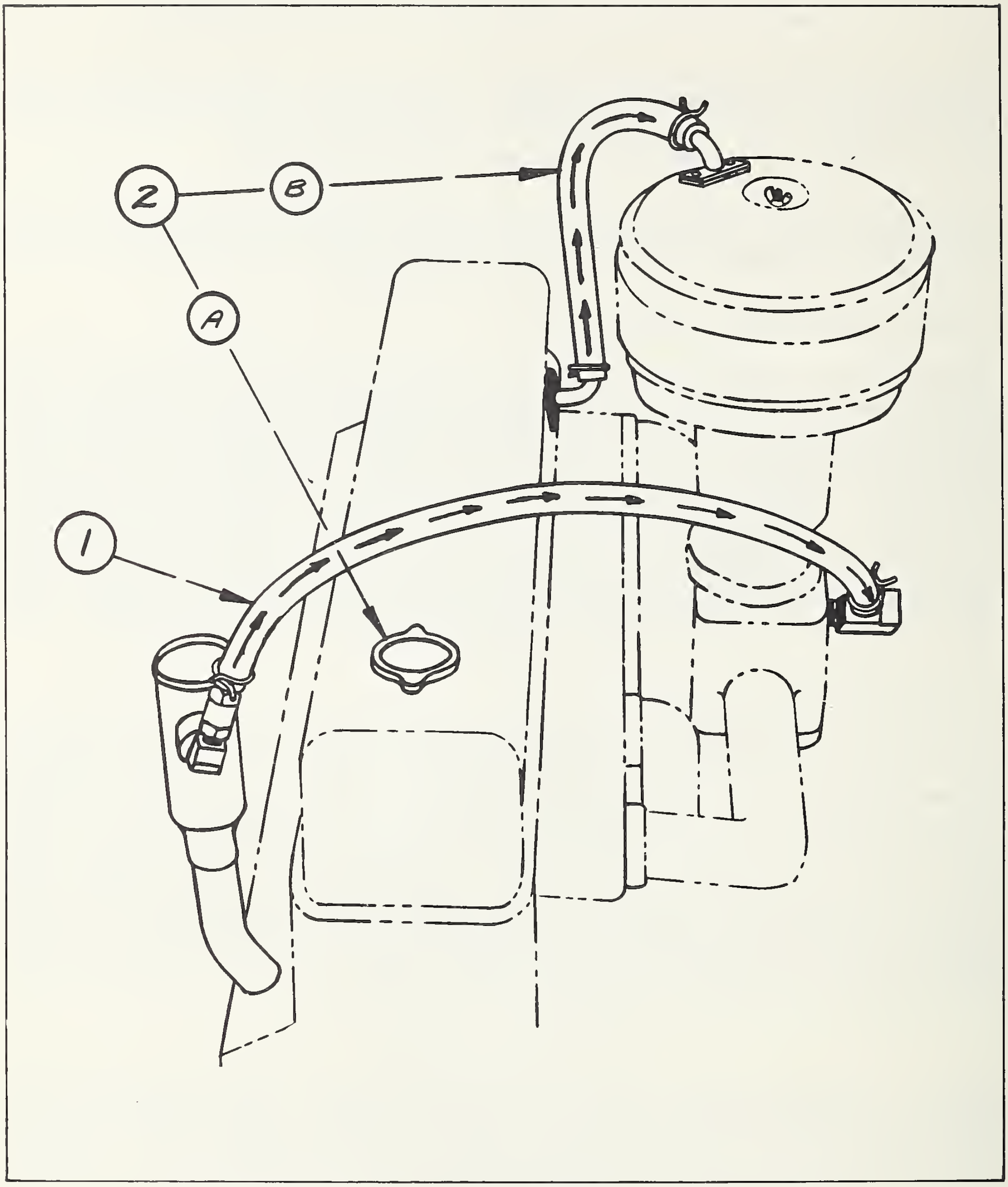


Figure 16. Positive crankcase ventilation system

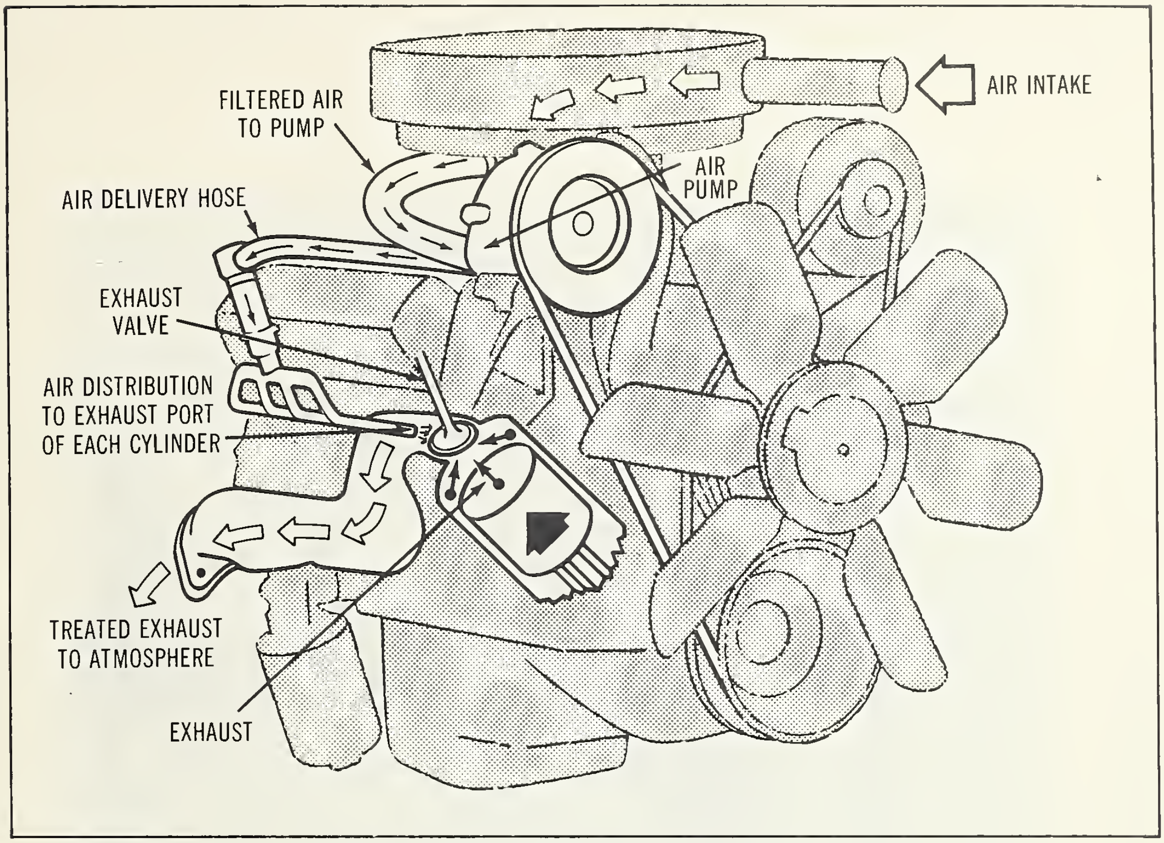
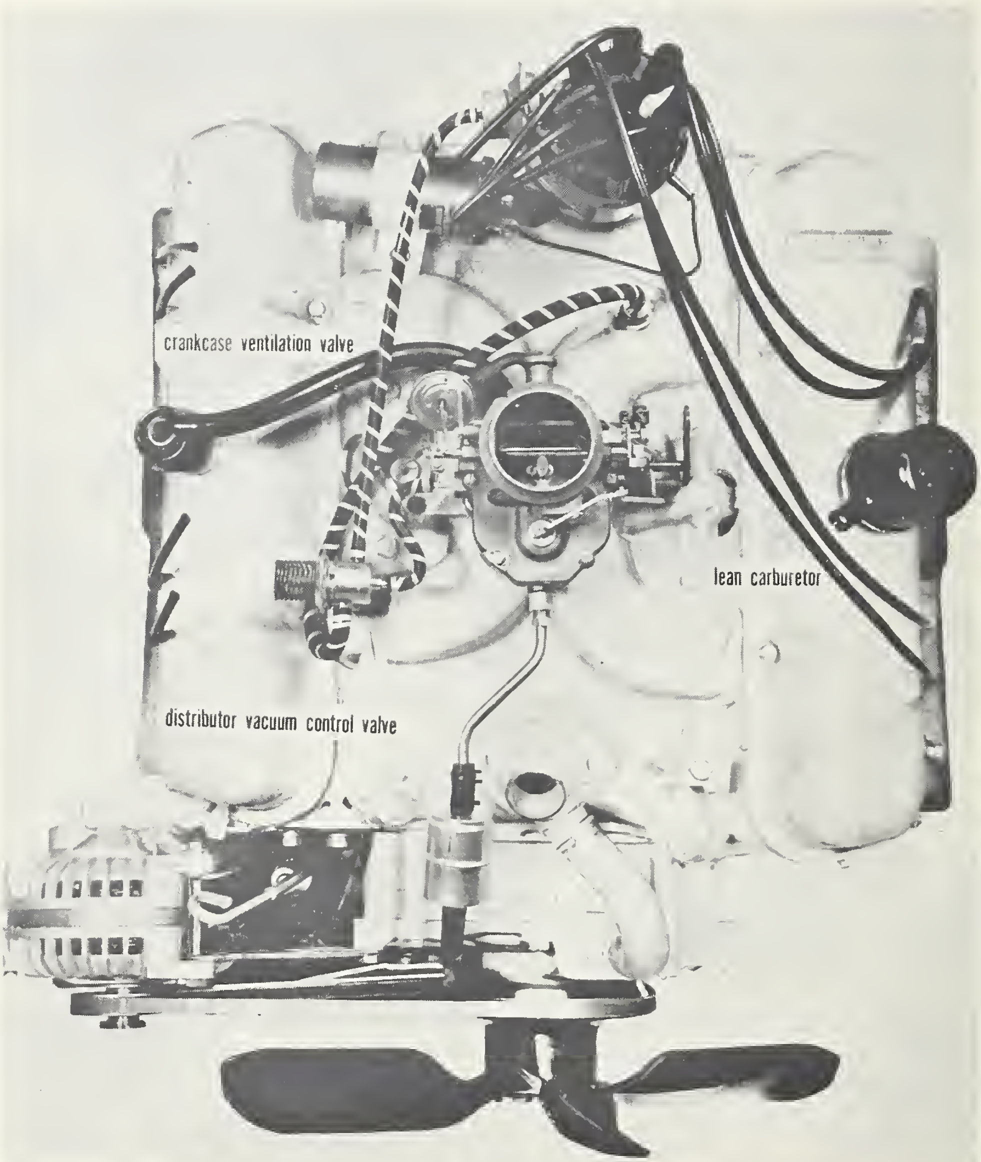


Figure 17. Air Injection Reactor

Induction Control

The induction device as fitted to Chrysler products (shown in Figure 18), involves a modified distributor, a modified carburetor, and a special ignition advance control valve. These modifications cause the engine to burn any smog-forming compounds which would otherwise be found in the exhaust gas.

The Chrysler induction device controls carbon monoxide and hydrocarbon emissions by providing optimum burning conditions in the cylinders through modified carburetion, altered distributor, and deceleration timing control.



CHRYSLER CORPORATION CLEANER AIR PACKAGE

Figure 18. Chrysler Corporation cleaner air package